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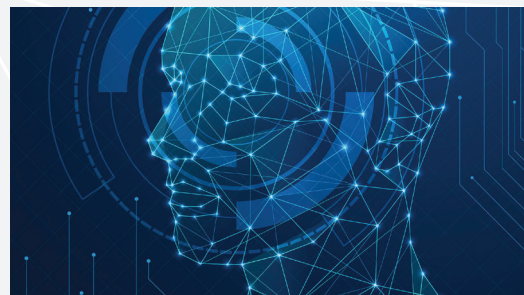
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# COMA'19

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## *Proceedings*

**Knowledge Valorisation in the Age of Digitalization**



30 January 2019 – 1 February 2019  
Stellenbosch, South Africa

Organised by  
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# Industry 4.0 and Digitalisation of Production Systems – How Remote Control of Robots and other Mechatronic Systems Can Contribute

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## Abstract

It is expected that ongoing digitalisation will drive the merger between the manufacturing world and the internet world, possibly leading to a next industrial revolution, currently called "Industry 4.0". The driving forces behind this development are new business opportunities and competition advantages arising from mass production customisation as well as rapid individual product development and manufacturing. Key factors of the development towards Industry 4.0 are discussed. Threats and opportunities arising from these developments for future production are discussed. Actual examples from real-time customized manufacturing of consumer products are given. As mechatronic systems and industrial robots are widely used in manufacturing and in particular in assembly, it is discussed how they can be connected to and used in digitalised industrial systems. Different examples of remote controlled systems are presented, like remote controlled KUKA robot for handling and quality control, PLC-controlled equipment, drive systems, FESTO handling system and others. The architecture of an assembly cell is presented, where industrial robots are set-up for batch-one production or can directly receive control / production information on-line and in real-time over the factory network. Methods for remote maintenance and monitoring of systems over the internet and production operator support over the internet are presented as well.

## Keywords

Digitalisation of production, reconfigurable manufacturing systems, remote control

## 1 INTRODUCTION

The term 'Industry 4.0' was generated with the intention to describe the possible 4th industrial revolution which might be implemented by the 'digitalisation' of a wide range of industrial and production processes. The term digitalisation itself is not a very fortunate wording since e.g. digital control, data processing and even computer controlled manufacturing is well-established since many decades. However, the term has become widespread and is obviously used to describe the introduction and application of advanced digital methods in the industrial context. Networking plays a major role in digitalisation, therefore the merger of the internet world with the industrial world is considered to be one important part of the new developments.

## 2 KEY ELEMENTS, OPPORTUNITIES AND RISKS ARISING FROM DIGITALISATION OF PRODUCTION

### 2.1 Digitalisation of production – some key elements

It is still difficult to give an exact definition of Industry 4.0 and digitalisation of production. It rather makes sense to summarize some characteristic elements, which include [1], [2]:

- Merger of the Internet world and the production world.
- New methods of human-system-interaction, including online services more or less directly linked to production.
- Rapid connection of and rapid communication between (embedded) components, systems, users, including in particular physical components and systems.
- Distributed intelligence and, up to a certain extent, autonomous behavior of subsystems.
- Digitalisation throughout the complete supply chain.

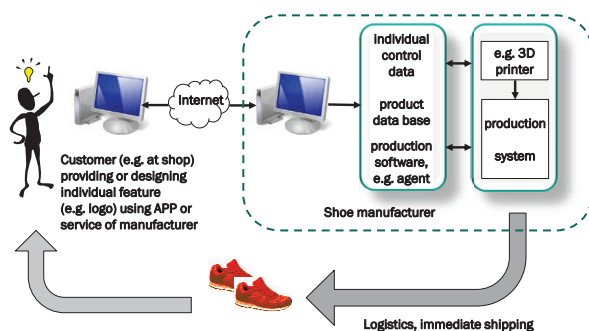
Digitalisation of production can make use of Cyber Physical Systems (CPS), software representation of physical products and systems (digital twins), collecting and processing of big amount of data (big data), Internet of Things (IoT) up to Internet of Everything (IoE).

### 2.2 Opportunities, consequences and risks

One major driver behind digitalisation in industry are many new business opportunities, which are expected and might be sparked by the commercial success of online companies in the consumer sector such as Amazon.

### 2.2.1 Mass product customisation / rapid individual product development and manufacturing

Expected benefits of digitalisation in industry are competition advantages by individualisation of products at short notice and at costs comparable or not tremendously higher compared to mass products. Additionally, some customers may even be prepared to spend extra money if they get individualised products (see example of sports shoe customization below). Individualisation of production is either based on further customisation of mass products (development and manufacturing of those) or will make use of new rapid development methods and new rapid production methods (like e.g. Additive Manufacturing equipment, 3D printers).



**Figure 1** – Application scenario from consumer products: Individualised sports shoe production

Figure 1 shows an example of such a procedure from sport shoe production: Design of individual features, like colour, logo or print on the shoes during the customer's visit and probing of the shoe in the shoe shop (or if one wants to buy with the risk of not-fitting shoes) at the own personal end device (PC, tablet, smart phone) using internet-based software of the shoe manufacturer. Immediate production of the individualised pair of shoes at the production plant and fast shipping by courier to the customer.

### 2.2.2 Rapid development and highly reconfigurable manufacturing and assembly equipment

It becomes obvious that customisation or individual product manufacturing requires rapid development methods as well as a new range of flexibility of production systems.

Rapid development can either be achieved by selection from pre-defined options (basically as it is done during the ordering process of a new car), or by integration of customer's elements or at least customisable elements (like a logo on a product or the size of a garment, or the size of furniture, or whatever other feature).

With respect to production systems, unfortunately the basic relation between flexibility and costs is that flexibility tends to be expensive. One reason is that highly flexible systems are much more complex than

mass production systems. There are a lot of examples: mass production systems are highly specialised and tuned to very low cycle time. On the other hand flexible robots, e.g. with vision systems, tend to be more expensive and slower in cycle time. The key to success in future will be to reduce production costs of individualised products. One appropriate measure can be to reduce the time for system reconfiguration or even for new set-up of production systems (see 'factory-in-a-day' project [3]). Looking to the assembly section of production systems, there are a number of components which offer a new range of flexibility. One example for highly reconfigurable equipment is the BOSCH APAS robot and manufacturing system. APAS consists of a mobile robot arm which can easily and rapidly be placed e.g. at an assembly spot and which allows fast and user friendly programming.

Since humans still provide a maximum of flexibility in production, the focus on human-machine interaction and collaboration becomes once more very important. The number of robots designed for human-robot collaborations was highly increasing over the last years. Examples are the Universal Robot types, KUKA iiwaa, ABB YuMi.

Even the previously mentioned APAS robot is covered by a sensor skin which protects both human and robot in case of collisions. The system forms therefore a step also in the direction of flexible human-robot collaboration.

### 2.2.3 Risks and crucial factors for success of digitalisation

It becomes obvious that Industry 4.0 leads to considerably increased complexity. Additionally to complexity, the following issues seem to be major risks and are often hurdles of digitalisation in production:

- Data security,
- physical system safety,
- customer acceptance,
- human qualification issues,
- investments and costs.

seem to be major risks and are not seldom hurdles of digitalisation in production.

Consequently, key issues for the (technical **and** commercial) success might be:

- Data and communication protection,
- protection of physical production equipment and systems against damage caused by unauthorized or incorrectly generated procedures,
- standardisation (e.g. of reference models, interfacing etc.),
- reduction of complexity and implementation of convenient functions for users, development of easy-to-use online services.

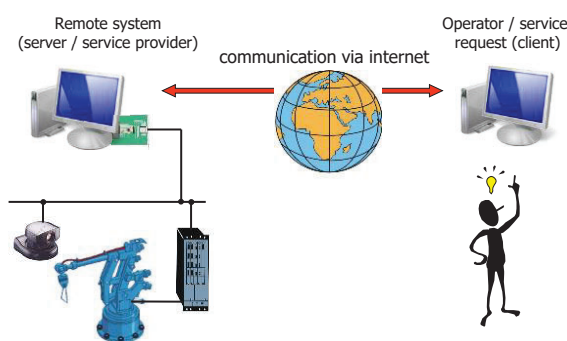


The implemented examples of digitalisation detailed in the following sections include also some examples how to overcome one or the other of these hurdles.

### 3 INCREASING AND DRIVING FLEXIBILITY OF PRODUCTION: METHODS FOR AND OF DIGITALISATION

#### 3.1 Production equipment and the Internet

Figure 2 shows the general approach of human-machine interaction over the internet. This was implemented in one of our laboratories. More than 10 physical systems, including industrial robots, handling systems, drives, PLC-controlled and other equipment can be accessed, observed by interactive web-cams and even controlled over the internet [4].



**Figure 2** – General scenario of implemented internet access to production equipment

Here, we are in particular interested in some of the described key issues of digitalisation, namely

- the protection of physical production equipment and systems against damage caused by unauthorised or incorrectly generated procedures,

as well as

- the reduction of complexity and implementation of convenient functions for users and development of easy-to-use online services.

Therefore the implementation allows access

- from everywhere,
- at any time,
- by anybody.

In particular, to allow access by anybody is the major challenge with respect to the physical systems' safety, because this includes no protection by password or the like, and allows access for completely unknown users.

To learn more about system protection, the method we apply are different access levels for the users, depending on the features of the different systems. In one example (handling system) we allow full graphical and text-oriented user programming via the internet because in this case there is no danger of mechanical collision with the environment.

The remote control of a KUKA industrial robot is done by a number of predefined actions for workplace handling, measurement procedure etc. Sensor and status data generated during operations are transferred to and displayed on the remote client's system.

Closed-loop controlled systems can be tuned by changing control parameters and the influence of user-generated disturbance can be observed.

The technical implementation of the remote access to a few of the mentioned systems and devices is explained in section 5. More implementation details as well as actual remote control access are provided via [4].

#### 3.2 How product configuration and reconfiguration of assembly systems can be supported by digitalisation

Digitalisation can help to manage the mass customisation of products. One of the enablers for mass customisation is 'customer-driven design and manufacturing' [5]. A digital instrument for this are online product configurators. These are web-based software applications for designing products that are precisely tailored to the individual needs of customers. A product configurator makes it possible to choose between product features, product options and technically feasible combinations. In mass customisation, this is the necessary link between customer-specific production and mass production. The configurator allows the customer to design the product to a certain degree by himself.

From the customer's point of view, the following advantages arise [6][7]:

- **Optimum fulfilment of requirements**, because the customer composes the product according to his specifications.
- **Avoiding of misconfigurations**, for products with many variants, a set of rules can prohibit incorrect selection options.
- **Reduced delay time** as no quotes have to be created, the price can be displayed during the configuration process.

The company can also gain advantages such as [6][7]:

- **Greater customer loyalty** - individual configuration increases emotional connection to the product.
- **Cost reduction** as no or fewer salespersons are required.
- **Amount of tied-up capital is reduced** as many combinations do not have to be pre-produced.

Flexible and reconfigurable manufacturing systems (RMS) are used to enable the production of individual products. These are necessary to react to changes on the market [8]. The six core features of a RMS defined by [9] are:

1. Customisation (flexibility limited to part family).
2. Convertibility (design for functionality changes).
3. Scalability (design for capacity changes).
4. Modularity (components are modular).
5. Integrability (interfaces for rapid integration).
6. Diagnosability (design for easy diagnostics).

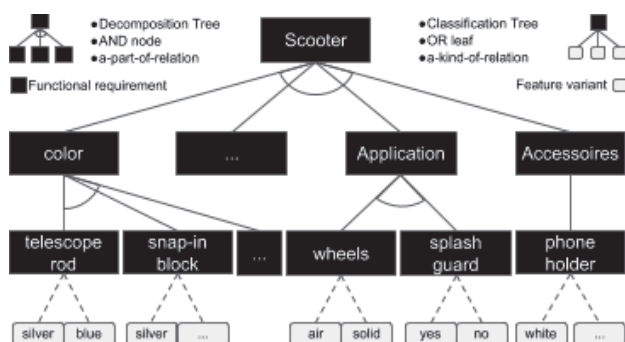
In order to be able to fulfill these points, networkable systems, which have access to a company-wide interconnected information network, are necessary.

## 4 IMPLEMENTED EXAMPLE FOR HIGHLY FLEXIBLE PRODUCT CONFIGURATION AND ASSEMBLY

### 4.1 Concept for customising and assembling a multivariant product

#### 4.1.1 Customisable mass product

The product used is a city scooter with some interchangeable parts. E.g. different colored parts can influence the appearance of the scooter. It is also possible to adapt the product to customer requirements by selecting different wheels or add optional accessories like a mobile phone holder. To get an overview of the possible variants, a tree structure of the scooter product family was created as shown in figure 3 using the presentation scheme of [10]. The total number of possible product variants results from the number of feature variants of each functional requirement. With our selection options, the total number of variants is 256.



**Figure 3** – Excerpt from the Product Family tree of the scooter

#### 4.1.2 Front-end, backend and Database

Because JavaScript (JS) is one of the most popular programming languages [11] of the last years and almost the only one in the Front-end area [12], we decided to use the MEAN stack. This consists of the following components:

- **MongoDB** - NoSQL Database which stores the data in JSON (JavaScript Object Notation) like format.
- **Express.js** - Server-side JavaScript Framework for web applications running on the Node.js platform.

- **Angular** - TypeScript (superset of JavaScript) based Front-end framework for web applications.
- **Node.js** - An implementation of a JavaScript engine that interprets the JS-code and converts it into machine-readable code.

This combination offers some advantages regarding the flexibility of the system. The use of NoSQL databases facilitates horizontal scalability, e.g. the enlargement of the product range. By using JavaScript in back- and Front-end, isomorphic and interchangeable code can be written. The JSON data format is transmitted through the entire communication path. Angular provides the platform to create a rudimentary product configurator.

#### 4.1.3 Assembly process

This process is handled simultaneously by two different workstations: A collaborative robot that handles the heavy and bulky parts. And a pick by light system where one worker takes the remaining parts and places them on the assembly jig. Each picking order is triggered by scanning the RFID tag on the assembly jig.

#### 4.1.4 Devices and systems

The collaborative robot is a UR10 type from Universal Robots. It is equipped with an electric 2-finger-gripper. Simple commands can be sent to the robot via the so-called dashboard server (TCP interface). This allows to remotely control the robot and to diagnose the condition.

The Pick by Light system is from the company Wibond and is comprised of a controller to which displays are connected in a line structure. The orders are managed by the Wibond software, which runs on a separate PC.

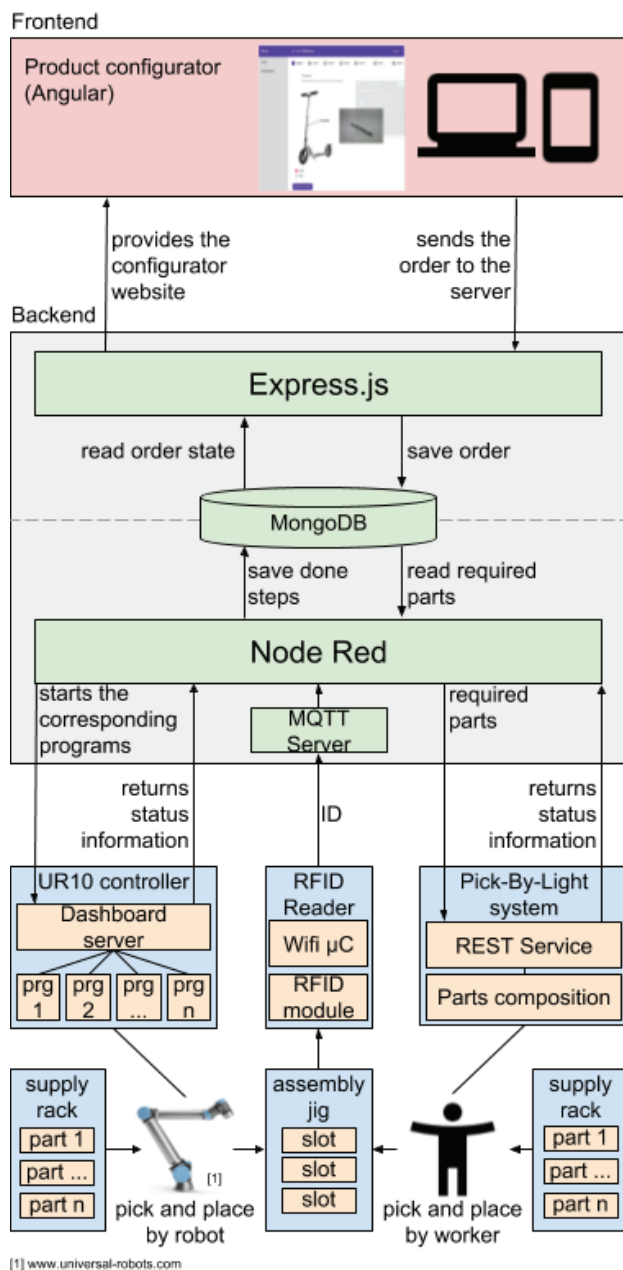
To assign the orders to RFID-chips we have developed an RFID reader. It is connected to the network via WiFi and it reads the ID and sends it to an MQTT server.

The intermediate layer on the software side for networking between the devices as well as for implementing the interface to the database is handled by Node Red. This is a graphical programming environment to connect e.g. devices with different communication protocols. It is also based on Node.js and exchanges data between nodes with JSON objects.

## 4.2 Process flow

The description of the process flow refers to figure 4. First, the customer visits the product configurator website provided by the Express app. Then the customer can compose the scooter according to his requirements and send the order back to the server. This is then saved as a JSON document within the Mongo database. The next step is then initiated at the respective workstation. In our scenario, the assembly process is the first workstation, but the concept can also be extended to subsequent work steps. When an empty assembly jig arrives at the workstation, a

RFID chip is scanned. Because this is the first step, the ID of the assembly jig is assigned to the next job in the queue based on a priority. There are several programs on the robot, each program being assigned to a specific part. The programs are triggered by Node Red depending on the required parts and the robot starts to pick up the parts and place them on the assembly jig. A similar situation applies to the Pick by Light system: depending on which parts are required from the supply rack, the display lights up on the corresponding compartment and thus shows the worker which parts and how many he has to take out. Then he puts the parts also on the assembly jig. The feedback of the systems is received by Node Red and is recorded in the database.



**Figure 4** – Information flow of the configuration and assembly process

### 4.3 Possible extensions

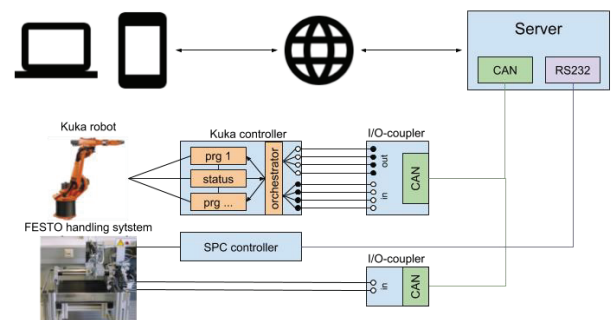
In our prototype implementation the entire backend runs on a local server. It is also an option to run the database and Express app on a cloud and use the local server with Node Red as edge cloud. In this way, several geographically separated locations could also be connected. If additional accessories or variants are added, they can also be integrated, for example by creating a new robot program and linking it to the part number. The principle is not limited to the assembly process and can also be applied to subsequent work steps.

## 5 IMPLEMENTED EXAMPLPES FOR REMOTE CONTROL OF PRODUCTION EQUIPMENT VIA THE INTERNET

Because not all, and in particular older, production systems are networkable from the beginning, the above concepts cannot always be applied. As a solution, various devices and systems were extended so that they can be controlled by a higher-level server. For demonstration purposes, a web interface was created to control them remotely via web browser.

### 5.1 Remote controlled Industrial Robot

The schematic connection of the individual components can be seen in Figure 5. The existing KUKA robot system provides several digital inputs and outputs. These are connected to a server via CAN-fieldbus (CAN: Controller Area Network) using an I/O-coupler. Various robot programs can be selected and started via a web interface. The corresponding program number is written as binary code to the outputs of the IO-Device. An orchestration program on the robot controller interprets the code and starts the requested program. The system and program status are constantly checked and transmitted to the remote client, as well as measurement values from a distance sensor attached to the robot.



**Figure 5** – Scheme for internet controlled devices

### 5.2 Remote controlled Handling system

This is a 2.5-axis pneumatic handling system which is programmable according to DIN 66025/ISO 6983 (G-Code). A web interface to the system was

developed where user programs can be generated and uploaded to the remote system. Subsequently, the commands are transmitted from the server to the controller via serial interface. It is also possible to read the current position of the axes through the serial interface, but only with a low refresh rate. Therefore a CAN module with analogue inputs was installed which captures the values of the analogue measuring system and outputs them in 30 ms cycles. This allows to visualise the real trajectory. Figure 6 shows the visualisation of the web interface. The black lines show the direct connection of the target points and the green dots are the real waypoints executed by the point-to-point controller.



**Figure 6** – Control and visualisation web interface of the Handling system

## 6 CONCLUSIONS

The presented methods and examples show how RMS can be implemented in different ways, using modern technologies. This includes web technologies for Front-end development, building backend solutions with database connection and networking production systems with each other and with higher-level systems.

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## 8 BIOGRAPHY



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